UNIVERSITÉ DE MONTRÉAL

CENTRE DE RECHERCHE SUR LES TRANSPORTS

CASE POSTALE 6128, STATION A, MONTRÉAL, QUÉBEC, H3C 3J7

THE EFFECT OF DIFFERENT VEHICLE TYPES ON CAPACITY

by

David Branston

Université de Montréal
Publication # 22 - Centre de recherche sur les transports
Juin 1975

Dépôt légal - 1er trimestre 1978

Introduction

The capacity of a highway is influenced by its geometrical characteristics and also by the composition of traffic which uses it. The accuracy of estimates of the capacities of new or existing highways will thus depend on our ability to predict the effects of different vehicle types on capacity. For a highway on which traffic is not affected by the influences of controlled intersections, it is possible to assess the relative effects of different vehicle types on its capacity by comparing the time headways, or inter-arrival times, associated with the different vehicle types under capacity flow conditions. This approach has been adopted by Gwynn[1] in calculating passenger car equivalents for trucks in express and local lanes of freeways in the U.S.A. Gwynn simulated capacity conditions by eliminating all headways greater than 9 secs. He then obtained passenger car equivalents for trucks by forming the ratio of their mean time headway to that of passenger cars at a number of sites with varying traffic composition.

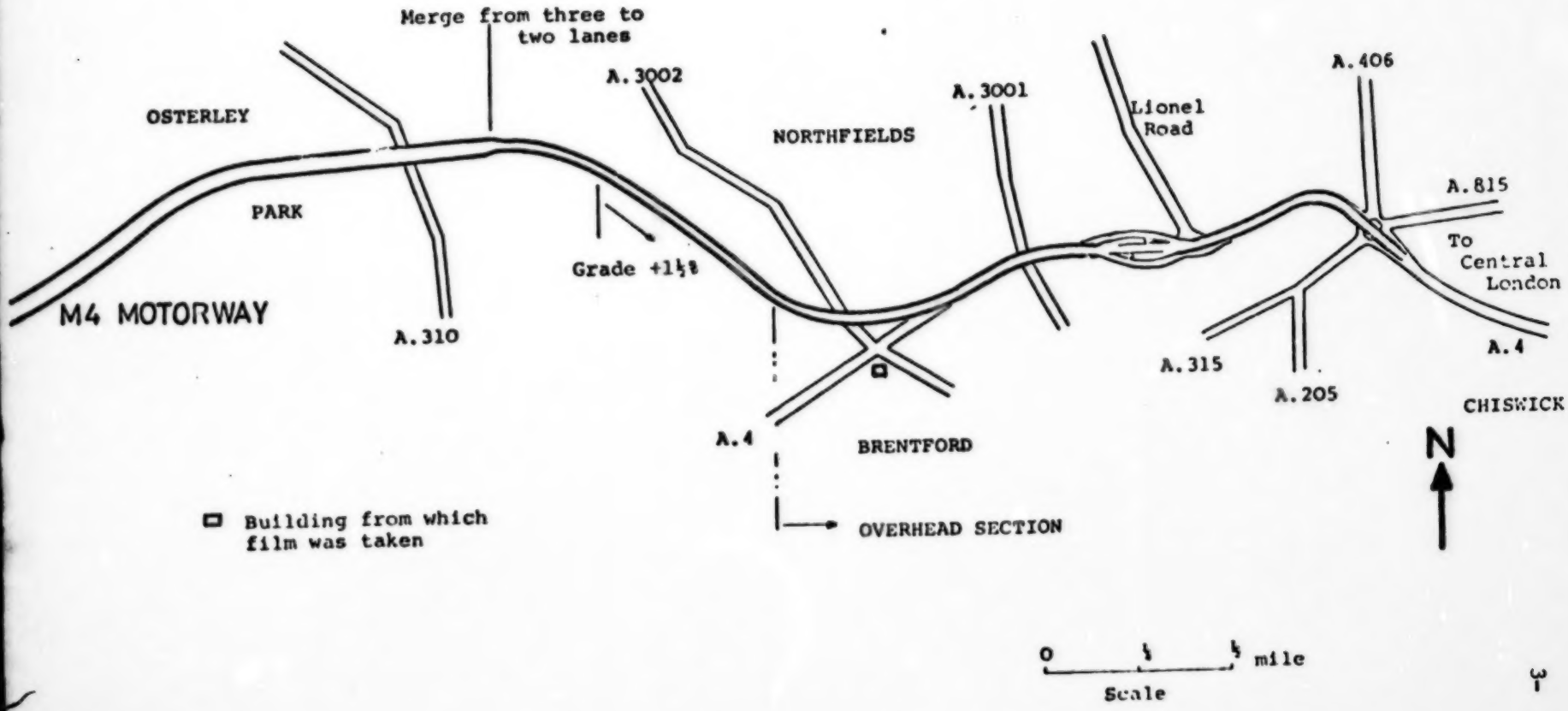
This paper describes some results obtained by the author from the M4 motorway in west London, which give an insight into the effect of different vehicle types on the capacity of this road. The approach used is broadly similar to that adopted by Gwynn, but the analysis is extended to separate the effects of vehicle length and of vehicle spacing, front to rear, to the vehicle ahead.

The Data Base

The M4 motorway is one of the main road traffic routes from south Wales and south-west England to London. It serves as the major road link from Heathrow Airport to London, and during morning and evening peak periods it also becomes a heavily trafficked commuter route. Figure 1 shows the section of the M4 from Osterley Park, west of London, to Chiswick, where it joins the A4 trunk road. Over most of its length, the motorway is built at ground level with three lanes in each direction. However just east of Osterley Park there is a reduction in width from three to two lanes followed by a ½ mile long incline with an average gradient of 1½%. This incline leads to an elevated section, approximately 40 ft above ground level, which stretches a distance of some 2 miles to Chiswick.

The combined effect of the merge and incline is to form a bottleneck which restricts flow on the eastbound carriageway into London close to the entrance to the two lane section. The demand during the morning peak period regularly exceeds the capacity of this bottleneck, and queues form on the eastbound three lane carriageway behind it, sometimes extending back for a distance of 5 miles. It is thus possible to obtain information on vehicle behaviour on the M4 under capacity conditions by collecting data at, or just downstream of the eastbound bottleneck during morning peak periods.

Figure 1 PLAN OF M4 MOTORWAY FROM OSTERLEY PARK TO CHISWICK



Data for this study were collected during the morning peak period of a Tuesday in 1972 using time-lapse photography, 16 mm films being taken from the building shown in Fig. 1. This building overlooks a relatively level stretch of the overhead section located just downstream of the top of the incline, and the camera position allowed coverage of approximately 280 ft of this level stretch. The data collection and analysis procedures have been described more fully elsewhere[2]. The complete data set includes vehicle speeds, lengths, arrival times at a fixed reference line, distance and time headways, and a classification by vehicle type. Six types of vehicle classification were used: car or light van, medium or heavy van (Ford Transit, etc.), bus or coach, non-articulated lorry, articulated lorry and motor cycle. The bus/coach category included those airport buses which were pulling luggage trailers whilst the motor cycle category included motor cycles with sidecars.

The periods during which the slow and fast lanes of the two lane section were working to capacity were obtained using an automated procedure developed by Breiman and Lawrence[3]. This procedure enables periods during which flow is approximately constant to be determined. The constant, capacity flow periods thus obtained for the slow and fast lanes were of duration 35½ mins and 47½ mins respectively, and the measured capacity flows were 1770 vehs/hr and 2480 vehs/hr, respectively.

Data analysis

For the purposes of this study, the headway of each vehicle was measured from its rear to the rear of the preceding vehicle. In this way, the times occupied by a vehicle of a particular type due to both its spacing

to the vehicle in front and its own length were included in its headway. The means of time headways so obtained for different vehicle types are shown in Table I for the slow and fast lanes.

The headways of cars and vans in the slow lane are significantly larger at the 5% level than their counterparts in the fast lane. The headways of other vehicle types are not significantly different from their counterparts in the fast lane, although, with the exception of the bus/coach category, they are consistently larger. Classifying buses, articulated and non-articulated lorries as heavy vehicles, the proportions of heavy vehicles in the slow and fast lanes are 17% and 2% respectively. Hence the mean time headways of different vehicle types, including cars, appear to increase as the proportion of heavy vehicles increases. A similar result was found by Gwynn in the U.S. study, average headways of all vehicle types increasing as the percentage of trucks increased. The results of Table I also show, as may be expected, that mean time headway increases with the physical size of different vehicle types for both slow and fast lanes; in both cases, the smallest headways are associated with motorcycles, and the largest with articulated lorries.

Whilst the results of Table I show *how* time headways vary both between vehicle types within a given lane and between lanes for a given vehicle type, they do not explain *why* such variations occur. They do not for example explain whether differences in headways between vehicle types within a lane are caused simply by differences in vehicle lengths. Neither do they enable assessment of the effect on headways of possible differences in speed between the slow and fast lanes. To determine the factors behind the observed headway variations, it is thus

TABLE I - Time headways associated with different vehicle types on the M4 during capacity flow conditions.

Vehicle type	Sample size	Mean time headway (secs)	Standard error (sec)
Slow lane			
Car	807	1.702	0.041
Van	47	2.050	0.233
Bus/coach	10	2.221	0.198
Non-artic. lorry	119	3.335	0.269
Artic. lorry	42	4.890	0.574
M/cycle	7	1.572	0.513
Fast lane			
Car	1851	1.433	0.019
Van	52	1.507	0.111
Bus/coach	12	2.737	0.651
Non-artic. lorry	19	3.005	0.482
Artic. lorry	2	3.415	1.287
M/cycle	8	0.797	0.085

necessary to divide the headways into their length and spacing (front to rear) components. The length component of a time headway, i.e. the time for which the reference line is physically covered by a vehicle, is often called the 'occupancy' and this term is used throughout the rest of this paper. Table II shows mean time occupancies, vehicle lengths and speeds in the slow and fast lanes. Motor cycles are excluded from this table and also from the future analysis of spacings, primarily because their freedom of lateral movement within a lane sometimes enabled them to pass the reference line alongside a vehicle in the same lane. Under such circumstances the effect of their presence on other vehicle types, and *vice versa*, is difficult to assess.

Table II shows that within both lanes the mean speeds of the different vehicle types are essentially equal. This yields the almost trivial expected result that increases in the time occupancy of different vehicle types within a lane are almost totally caused by increases in vehicle length. In his U.S. study, Gwynn found that; "It appears that the number of trucks in a queue of 11 vehicles has an effect on the average headway in the queue. The greater the number of trucks, the larger the average headway". The results given in Table II show that this result would be expected even if there was no difference in the spacings adopted by trucks and cars.

From Table II it can be seen that the average speed of any vehicle type is approximately 10 ft/sec higher in the fast lane than in the slow lane. In addition, with the exception of the articulated lorry category

TABLE II - Time occupancies associated with different vehicle types on the M4 during capacity flow conditions.

Vehicle type	Mean time occupancy (sec)	Standard error (sec)	Average length (ft)	Average speed (ft/sec)
Slow lane				
Car	0.246	0.001	12.9	52.4
Van	0.273	0.005	14.0	51.7
Bus/coach	0.655	0.038	33.4	51.9
Non-artic. lorry	0.472	0.008	23.7	50.7
Artic. lorry	0.784	0.020	40.4	51.9
Fast lane				
Car	0.218	0.001	13.0	61.3
Van	0.226	0.004	13.9	62.5
Bus/coach	0.542	0.021	33.4	61.5
Non-artic. lorry	0.359	0.014	22.3	62.7
Artic. lorry	0.482	0.043	29.9	62.3

for which there were only two observations in the fast lane, for each vehicle type the average length of vehicles in the slow lane is approximately equal to that of those in the fast lane. Hence the increase in time occupancy of the different vehicle types in the slow lane over their counterparts in the fast lane, which can be seen in Table II, is almost totally attributable to the lower speed in the slow lane.

Few of the differences between the mean time occupancies of cars and of other vehicle types in Table II explain completely the differences in their respective headways in Table I. The difference in occupancies between the articulated lorry and car categories in the slow lane is, for example, 0.22 secs, whilst the difference in their headways is 3.19 secs. The latter is thus also affected by the spacing component of the headway.

Table III shows the mean spacings associated with the different vehicle types in the slow and fast lanes. Also shown are the percentages of each vehicle type which were classified as following the vehicle in front. Hence 1693 cars, or 91.5% of cars in the fast lane were classified as following. Time headway and relative speed criteria were developed to determine when a vehicle was following and were used to estimate the percentages of Table III.

The results in Table III on mean distance spacings for the bus/coach category and the percentages of this vehicle type which are following indicate a difference in the behaviour of buses in the slow and fast lanes. In the slow lane all buses are following whilst in the fast lane only just over half are following. Hence in the slow lane both distance and time

TABLE III - Spacings associated with different vehicle types on the M4 during capacity flow conditions

Vehicle types	Mean distance spacing (ft)	Standard error (ft)	Mean time spacing (secs)	Percentage of this vehicle type following (%)
Slow lane				
Car	79.3	2.8	1.456	90.5
Van	95.5	15.4	1.776	85.1
Bus/coach	82.7	5.9	1.567	100
Non-artic. lorry	145.7	13.8	2.863	59.4
Artic. lorry	213.3	29.0	4.106	52.4
Fast lane				
Car	75.4	1.3	1.214	91.5
Van	81.0	7.3	1.281	88.5
Bus/coach	138.6	42.2	2.194	58.3
Non-artic. lorry	167.6	29.9	2.646	52.6
Artic. lorry	186.7	91.7	2.933	50

spacings adopted by buses are approximately equal to those adopted by cars. The difference in the time headways given in Table I for these two vehicle types for the slow lane is thus almost completely attributable to the greater length of buses. The result that the mean distance headway of buses in the fast lane is larger than that in the slow lane is probably caused by the presence of non-following buses in the fast lane. The increase in distance spacing is sufficient to make the bus/coach category the only one in which the mean time spacing, and also the mean time headway,in the fast lane, is larger than that in the slow lane. It is not immediately obvious why all buses in the slow lane are followers when some buses in the fast lane are non-followers. However, it is possible that whilst all buses are capable of maintaining the speed required to be following vehicles in the slow lane, not all buses which travel in the fast lane are capable of maintaining the higher speed required of followers in that lane under capacity conditions.

With the exception of the bus/coach category the mean distance spacings adopted by each vehicle type in the slow lane are approximately equal to their counterparts in the fast lane. In fact none of the differences between comparative slow and fast lane distance spacings are statistically significant at the 5% level. Hence the increases in time spacings of vehicle types in the slow lane over their counterparts in the fast lane are mostly caused by the lower speed in the slow lane. Combining this result with that found earlier, that the larger time occupancy of vehicle types in the slow lane than their counterparts in the fast lane is also caused by the lower speed in the slow lane, it can be seen that the increase in mean time headway between lanes for different vehicle types is mainly attributable

to the difference in speed between the two lanes. The fact that the lane with the lower speed is also that with the higher proportion of heavy vehicles tends to suggest that the average speed of a lane under capacity flow conditions decreases as the proportion of heavy vehicles increases. Hence the earlier noted increase in average time headways between the lanes with the corresponding increase in the proportion of heavy vehicles is probably caused by the average speed decreasing as this proportion increases, and the average time headway increasing as the average speed decreases.

With the exception of the bus/coach category in the slow lane there is a general increase of both mean distance and time spacings with vehicle size within either slow or fast lanes. This is accompanied by a decrease in the proportions of the different vehicle types classified as following with increasing vehicle size. Hence the increase within a lane of mean time spacing and mean time headway with increasing vehicle size is probably caused by the inability of as large a proportion of bigger, heavier vehicles to follow the vehicle in front. The fact that the M4 site is at the top of an incline may cause the increases for heavier vehicles, with their lower power-weight ratios, to be larger than would occur at a comparative level site.

Combining results on time headways given in Table I for the slow and fast lanes, it is possible to obtain passenger car equivalents, in a capacity sense, for each vehicle type by forming the ratio of its mean headway to that of cars. The resulting values for the M4 are: Van, 1.2; Non-articulated lorry, 2.2, and Articulated lorry, 3.2. No value was obtained for the bus/coach category because of the difference in bus behaviour

in the fast and slow lanes noted in the discussion on the spacing results. Gwynn found, using a similar definition, that on local and express lanes in the U.S.A. "a truck does not appear to be equivalent to as many as two passenger cars from a headway or volume standpoint". The passenger car equivalents found for non-articulated and particularly articulated lorries on the M4 thus suggest that lorries have more effect on its capacity than do trucks on the capacity of Gwynn's site. However as has already been pointed out, this may be partly due to the incline just upstream of the M4 site. It would seem worthwhile to obtain comparative passenger car equivalents from other sides.

Conclusion

The following conclusions have been made on factors affecting the capacity of the two lane M4 motorway section:

1. There is an increase in the average time headway of all vehicle types except buses in the slow lane over the fast lane. As average distance spacings and lengths of each vehicle type are approximately equal in slow and fast lanes, this increase is almost entirely due to the lower speed of vehicles in the slow lane. The lower speed of all vehicles in the slow lane is probably caused by the higher proportion of heavy vehicles in that lane.

2. There is a difference in the behaviour of buses in the slow and fast lanes. In the slow lane all buses are following directly behind the vehicle in front whilst only just over half the buses in the fast lane are

following. The latter result may be because not all buses which travel in the fast lane are capable of maintaining the high speed necessary to be a follower in that lane under capacity conditions. The difference in the mean time headways of cars and buses in the slow lane is almost entirely caused by the latter vehicle type's greater length.

3. There is an increase in the mean time headway within lanes with physical vehicle size. This is partly attributable to the increase in length of vehicles, but is mainly caused by the inability of large, heavy vehicles to follow directly behind the vehicle in front.

4. Under capacity flow conditions the mean time headways of non-articulated lorries on the M4 are 2.2 times as large as those of passenger cars, and the mean time headways of articulated lorries are 3.2 times as large as those of passenger cars. These values are higher than those obtained by Gwynn for local and express lanes in the U.S.A., but this may be due to the presence of an incline just upstream of the M4 site.

ACKNOWLEDGEMENTS

This research was carried out partly at the Traffic Studies Group, University College London, where it was supported by the Science Research Council. The research was supported in Canada by the Transport Development Agency.

REFERENCES

1. GWYNN, D.W. Truck equivalency. Highway Res. Record 199, p. 79, 1967.

2. BRANSTON, D.M. Data collection from the M4 motorway. Presented at Universities Transport Study Group Seminar on "Instrumentation for Traffic Data Collection", Sheffield, England, 27th September 1974. To appear in the press.

3. BREIMAN, L. and LAWRENCE, R.L. Time scales, fluctuations and constant flow periods in uni-directional traffic. Transp. Research, 7 (1), 77-105, 1973.